

# “Sponge City” in China—A breakthrough of planning and flood risk management in the urban context

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## ABSTRACT

Surface water flooding is currently viewed as the most serious water-related issue in many of the China's large cities due to rapid urbanization, land-use change and the process of rapid socio-economic development. In 2014, the People's Republic of China established the concept of the 'Sponge City', which will be used to tackle urban surface-water flooding and related urban water management issues, such as purification of urban runoff, attenuation of peak run-off and water conservation. The concept is being developed to make use of 'blue' and 'green' spaces in the urban environment for stormwater management and control. It is envisaged that related practices will enhance natural ecosystems and provide more aesthetically pleasing space for the people that live and work in urban environments, in addition enabling nature-based solutions to improve urban habitats for birds and other organisms.

Until recently, grey infrastructure and hard engineering-based management approaches have been adopted in the rapidly developing Chinese urban environment as urban flood and drainage issues are predominantly managed by municipal water engineers. The Sponge City concept and related guidelines and practices will provide multiple opportunities to integrate ideas from eco-hydrology, climate change impact assessment and planning, and consideration of long-term social and environmental well-being, within the urban land-use planning process.

This paper aims to explicate the Sponge city concept and its development, and consider the implications of the transformation of urban land-use planning and urban-water management practice in China. To achieve the dual goals of sustainable water-use and better flood control (as targeted by the Sponge City concept), more effective development and implementation of land-use guidance and assessment tools (with explicit integration of urban flood-risk assessment, land-drainage guidance, climate projection methods, and assessment of long-term sustainability) are recommended.

## 1. Introduction

Urban flooding has become a major issue in China, but there is uncertainty about how to implement the most recent guidance for urban-drainage infrastructure to address the problem. The Chinese National Government is promoting the “Sponge City” concept and is funding the development of demonstration projects for concept in thirty pilot cities across the country (including megacities of Beijing,

Shanghai, Tianjin, and Shenzhen).

The Sponge City concept is similar to the Low Impact Developments (LID) approach in the United States (Pyke et al., 2011); Sustainable Urban Drainage Systems (SuDs) (Griffiths, 2017; Mitchell, 2005) and the Blue-Green Cities (BGCs) approach (Thorne et al., 2015) in the United Kingdom; and Water Sensitive Urban Design (WSUD) in Australia (Morison and Brown, 2011) or Low Impact Developments Urban Design (LIDUD) in New Zealand which combines the approaches

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adopted in the United States and Australia (Voyde et al., 2010; Van Roon, 2007). The Sponge City concept aims to (i) adopt and develop LID concepts which improve effective control of urban peak runoff, and to temporarily store, recycle and purify stormwater; (ii) to upgrade the traditional drainage systems using more flood-resilient infrastructure (e.g. construction of underground water-storage tanks and tunnels) and to increase current drainage protection standards using LID systems to offset peak discharges and reduce excess stormwater; and (iii) to integrate natural water-bodies (such as wetlands and lakes) and encourage multi-functional objectives within drainage design (such as enhancing ecosystem services) whilst providing additional artificial water bodies and green spaces to provide higher amenity value.

LID infrastructure such as bio-swales, rain gardens, pervious pavements and green roofs are often designed to mimic natural hydrological response (for example these measures are able to reduce the peak discharges in urban runoff land drainage system) and to absorb urban stormwater through soil infiltration, stormwater retention, storage, purification, recharge groundwater and improving water quality of the runoff (Everett et al., 2015; Qin et al., 2013). Such infrastructure however, are able to deliver additional benefits. The installation of swales and rain-gardens for example, can enhance urban greening and increase the overall area of urban green space. This in-turn can improve urban eco-system diversity by providing new habitats for a wider range of organisms (e.g. birds, butterflies and dragonflies, etc.). Careful planning of such infrastructure can also deliver multiple benefits to the general public by creating greater recreational space (e.g. urban park-lands) and improving the amenity value of a district or area (Wang et al., 2017).

Indeed, Xia et al. (2017) describe the “Sponge City” concept as a breakthrough for urban planning in China, as the concept and related guidelines and policy have the potential to enhance the principle of sustainability (by addressing ecological and socio-economic aspects), and encourage urban water-resource management (and flood risk management) to better integrate with the practice of urban planning and design (Fig. 1).

The major question is whether earlier adoption of this concept would have been capable of preventing the spate of severe urban surface-water flooding that has recently occurred in Chinese cities? For example, urban flooding in Beijing (in 2012) caused 79 deaths (English.news.cn, 2012), whilst similar events occurred in Guangzhou and Shenzhen in 2013 (Francesch-Huidobro et al., 2016). Interestingly, the Central Government was quick to stress that the cause of these

floods was the extreme nature of the rainfall, rather than a lack of drainage system maintenance. However, it was also concluded that even modern urban drainage systems had not been designed to handle increased runoff produced by the cumulative effect of reduced infiltration in the urban setting.

This is a key point. Surface-water flooding is not a new phenomenon in China’s urbanised and populated megacities, particularly during the annual monsoon season (Chan et al., 2014; Fuchs et al., 2011). Whilst, government-led urbanization and associated land-use change however, failed to consider the cumulative and integrated impact of reduced water infiltration (caused by increasingly concrete landscapes) on urban water management.

In response to flood-risk, hard-engineering control measures, such as construction of flood-water impoundments have been favoured in China for many years. For example, more than 97,000 dams have been built since 1950, most of the dams were built for providing water supply and irrigation before 1978, albeit partly due to an industrial drive for increasing hydro-power production. The major measures used in controlling fluvial/riverine floods has historically been to build dykes and enhanced flood diversions in China. Such impoundments are effective in controlling fluvial or riverine floods from upstream catchment areas, but it is becoming increasingly difficult to ensure protection of downstream areas due to rapid urbanization in China. Urban floodplain developments often need additional pluvial flood protection measures that promote infiltration and storage of stormwater during intense rainfall to prevent exceedance of the drainage system storage capacity to tackle pluvial or urban surface water floods (or waterlogging). Traditionally these have taken the form of detention basins or retention ponds but are increasingly being supported by wetlands, overspill areas and sub-surface storage.

This viewpoint article then, aims to provide a better understanding of the “Sponge City” concept in China by following two specific objectives. Firstly, it will investigate the background of the Sponge City concept to assess how it can be most effectively implemented. Secondly, it considers how Sponge City practice may influence existing urban water/flood risk management and urban land-use planning policies.

## 2. The sponge city concept: background and commonality with other similar practices

Since the “Open Door Policy” was promoted in the late 1970s in the People’s Republic of China (PRC), the country has experienced

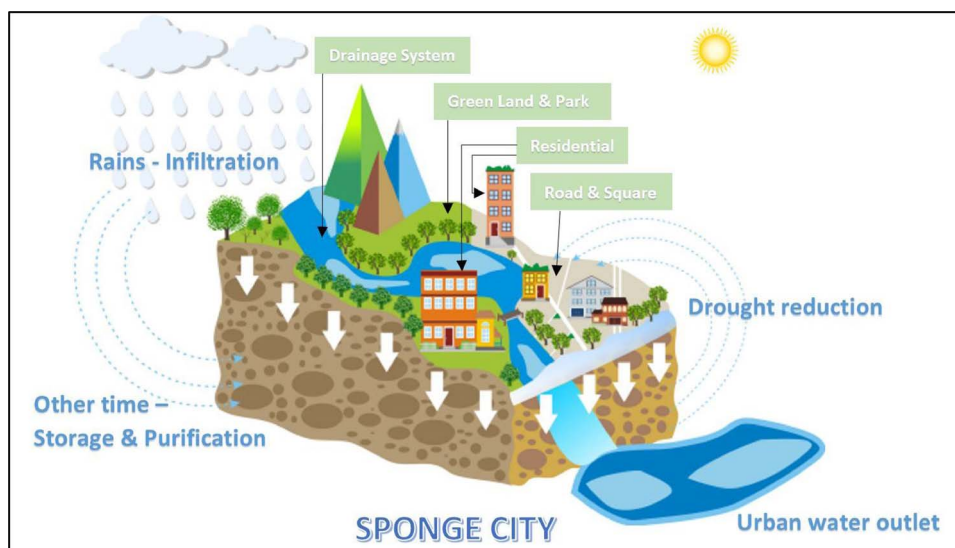


Fig. 1. Schematic diagram of the Sponge city concept.  
Source: Shuyang Xu.

unprecedented urbanization and socio-economic growth. The urban population has increased some four-fold compared with the 1978 (172.45 million) to approximately 771.16 million in 2015 (NBSC, 2016). A large urban population, the rate of urban population is 56.10% in 2015 that has developed to support centralised industrial and commercial developments (Guan et al., 2018; NBSC, 2016). In such a rapid process of urbanization, land-use change from natural landscape (e.g. green spaces, vegetation areas, forestry and soil surfaces) to urban land-use (e.g. commercial, residential and industrial) has been unprecedented. For example, 26.3% land-use change from the rural areas (including forest and vegetated lands) to urban areas from 1979 to the 2000s in the Pearl River Delta (Yeung, 2010). This drastic loss in natural capital (in the form of ecosystem services and surface water-bodies) equates to 10.4% of and across 16 cities in the Yangtze River Delta from 2000 to 2010 (Xu et al., 2014). In this time, previously semi-rural environments have been transformed by urban development into combinations of roads, buildings and various other forms of urban infrastructure.

In this way then, a reduction in permeable surfaces and rainfall infiltration has resulted in a lower retention capacity for stormwater in urban areas and less recharge of underlying groundwater. As a result, in most cities in China there is an over-reliance on the urban drainage systems, especially during the wet season when the most intense rainfall occurs. In response, the Sponge City program will promote greater use of LID infrastructure that increases rainfall infiltration and storage of urban stormwater by promoting the use of more permeable pavement and road materials; greater use of swales and infiltration channels (Fig. 2); and the creation of artificial wetlands within the urban parklands (Fig. 3). In addition to improving stormwater absorption and storage and thus reducing the volume of urban runoff, this type of infrastructure delivers multiple benefits such as enhancement of ecological functions and improvement of urban aesthetic value and creation of additional amenity space.

Currently in China, many urban drainage systems operate in exceedance of conditions for which they were initially designed. For

example in Shenzhen, the urban runoff discharge has been increased by 12.9% from the 1980s to the 2000s (Shi et al., 2007). This is perhaps not surprising, as the “Code for design of urban road engineering” (Ministry Of Housing And Urban-Rural Development, 2016) states that most Chinese cities are designed only for 1-in-1 year to 1-in-10 year return period events (Ministry Of Housing And Urban-Rural Development, 2016; Chan et al., 2014; Cheng, 2005). As a result, a number of cities have suffered recurrent flooding as their outdated drainage systems fail to cope with the intensity of typhoon/cyclonic-enhanced rainstorms and sub-tropical rainstorms.

From 2006 to the 2010s, more than 150 cities in China were affected by severe flooding, the direct damage for which cost more than 160 billion RMB (Li et al., 2015). Notably recent examples include the 2013 October flood in Shanghai and Ningbo and the 2013 May flood in Guangzhou and Shenzhen (Yu et al., 2015; Yang, 2014). These facts explain why Chinese municipal governments are committed to improving urban flood resilience and are eager to adopt the “Sponge City” approach introduced by the current Chinese President, Xi Jinping.

Presented first at a central urbanization work conference in December 2013, the “Sponge City” Concept aims to tackle increased flood-risk due to rapid urbanization and create an overarching concept that includes key components of urban water resources management, urban planning and sustainable development, including urban water body preservation, stormwater storage and water quality improvement. The concept was officially launched at the end of 2014 under the guidance of the Ministry of Housing and Rural-Urban Development (MOHURD), the Ministry of Finance and the Ministry of Water Resources (MWR) in the PRC government (Ministry Of Housing And Urban-Rural Development, 2014). The policy at first identified 16 cities for conducting pilot projects, and later expanded the list to another 14 cities. According to the “Guideline of Sponge City Construction”, the target of the approach is to increase the area of urban land able to absorb surface water discharges by approximately 20%, and to retain or reuse approximately 70% of urban stormwater by 2020; and further reuse up to 80% of stormwater by 2030s. This means that the ideology



Fig. 2. Permeable Pavement (left) and bio-swale (right) locate at Yanglin, NW China. Source: Faith Chan.



Fig. 3. Artificial wetland for stormwater purification and storage at Jiangbei District, Ningbo, E China.  
Source: Faith Chan.

of the Sponge City concept is not only addressing urban flood risk, but also taking a proactive approach to collection, purification and reuse of urban stormwater in Chinese cities to address future climatic extremes (floods and droughts).

### 3. Challenges to urban water management in China

In order to promote the development of a consistent Sponge City methodology which would include planning, purchasing raw materials and construction of drainage infrastructure, the financial investment needed to support pilot Sponge Cities projects is 1.2 billion to 1.8 billion RMB over a three-year period. The Sponge City is a major campaign and is providing opportunities for the new urban development strategy in Chinese cities (Wang et al., 2017). According to the Sponge City Construction guidelines, in the first stage of the program (from 2018 to 2020), pilot study areas should cover more than 20% of the city in which they reside (Ministry Of Housing And Urban-Rural Development, 2014). This is potentially quite a challenge as much of the existing urban infrastructure will most likely have been designed using conventional hard engineering approaches, which will make development more costly. For this reason, retrofit and reconstruction to Sponge City guidelines alone, have been estimated to cost 0.1–0.15 billion RMB per km<sup>2</sup> (Xia et al., 2017).

In over 90% of Chinese cities, the design of urban flooding mitigation measures is linked to traditional engineering infrastructure (i.e. floodgates, concrete infrastructure and oversized drains) that aim to drain urban discharges as quickly as possible to downstream outlets (larger rivers, lakes and coasts). In Shenzhen for example, the main drainage outlet is the Shenzhen River, which subsequently discharges into the Pearl River Estuary and the South China Sea (SZWB, 2012). Unfortunately, this approach is both costly and inflexible in accommodating unplanned urban expansion and increases in impervious urban land surfaces. With increased urban space, this approach is also unable to cope with intense rainfall events, and many Chinese cities (Guangzhou, Beijing, Ningbo and Wuhan (Yang et al., 2014; Liu et al., 2016; Tang et al., 2015, Shen, 2010)), have witnessed significant loss of lives (79 casualties at Beijing flood in July 2012) and economic impact due to flooding.

Another impact of increased urban population is water pollution. In light of seemingly unstoppable urban land-use expansion, non-point source pollutants (roadside emissions, domestic industrial and agricultural seepage and runoff) are increasingly discharged into, and

degrade urban rivers. Approximately 60–80% of urban water bodies (e.g. rivers, ponds, channels and culverts) in Shenzhen and many other towns in the Pearl River Delta for example, are known to have significant levels of pollution (level IV or below by the National Water Quality Standard GB3838) (Jiang et al., 2013; Du et al., 2010; Ouyang et al., 2006).

The Sponge City concept then, aims transform the urban planning process whilst promoting the conservation and creation of greener landscapes in urban areas. Implemented successfully, the concept will engage more effectively with future land-use and spatial planning and also improve urban ecosystem diversity and social wellbeing. Achievement of the Sponge City goals would result in greater conservation of rivers and other urban water-bodies and wetlands, and corresponding increases in other urban green spaces (e.g. vegetated areas, forests, farmlands). The concept however, will also allow the continued use of engineering infrastructure for urban runoff control and storage of stormwater during extreme rainfall events, an approach which would be something of a breakthrough in China. Such practice will provide opportunities to address wider urban water and environmental issues, that are currently addressed using grey infrastructures such as urban river channelisation, land-use drainage and flood control.

To aid the adoption and implementation of the Sponge City concept the “Code for the design of urban green space” (Ministry Of Housing And Urban-Rural Development And Ministry Of National Quality Standard Monitoring Bureau, 2016b) has been revised and officially published to align with the Sponge City guidance. In particular, the document emphasises a coordinated approach to the design and construction of urban green-space, particularly with respect to management of drainage discharge; the utility of space for stormwater storage; the relationship between soil type, infiltration, and discharge volumes; and minimum allowable discharge rates during the normal and wet conditions to maintain required soil field capacities. Furthermore, the “Code for design of urban road engineering” (CJJ37-2012) has also been revised to accommodate the requirements of Sponge City practice (Ministry Of Housing And Urban-Rural Development, 2016). Installation of LID infrastructure such as bio-swales on roadways require additional space between pedestrians, cycle lanes and roads for example: for this reason, the revised CJJ37-2012 urban road design code has included a new section (16 – Green infrastructure), to require urban roadways to reserve at least 1.5 m width for suitable green infrastructure.

Unfortunately, introduction of the Sponge City concept to the planning process may further complicate current practices as

Table 1

Table 2 Evaluation of common drainage infrastructure components. Adopted from [MINISTRY OF HOUSING AND URBAN-RURAL DEVELOPMENT \(2014\)](#).

	Function					Target			Economic cost		Suspended solids removal (%)	Aesthetic value
	Water storage	Infiltration	Reduce peak	Water purification	Ecological enhancement	Run-off volume	Peak run-off	Pollutant control	Construction	Maintenance		
Permeable pavement	x	●	✓	✓	x	●	✓	✓	Low	Low	80–90	Fair
Green roof	x	x	✓	✓	x	●	✓	✓	High	Middle	70–80	Good
Complex bio-detention	x	●	✓	●	x	●	✓	●	Middle	low	70–95	Good
Artificial pond	●	x	●	⊙	x	●	●	✓	High	Middle	50–80	Good
Artificial wetland	●	x	●	●	x	●	●	●	High	Middle	50–80	Good
Rain-garden	●	x	✓	✓	x	●	✓	✓	Low	Low	80–90	–
Bio-swales	x	●	x	✓	●	●	x	✓	Low	Low	35–90	Good
Vegetation buffer	x	x	x	●	–	●	x	●	Low	Low	50–75	Fair

infrastructure, operations and management systems (such as property and housing districts zone planning, and land drainage zones), have developed slowly over decades suggesting that existing infrastructure has a limited capacity to respond quickly to new concepts. The “Code for design of urban residential and properties zone planning” (GB 50180—93) revised and published in 2002 (first published in 1994) for example, indicates that developers and governmental construction agents should follow existing requirements for preservation of green spaces of up to 1 ha (urban parks, playgrounds and vegetation areas), and installation of drainage and pipelines for reliving the urban stormwater discharge (MHC, 2002). However, the code of practice has not yet been updated, as will be required for land-use planning in support of the latest Sponge City practice.

A similar situation arises for the “Code for design of outdoor waste water engineering” (GB50014-2006), revised and published in 2016 (Ministry Of Housing And Urban-Rural Development And Ministry Of National Quality Standard Monitoring Bureau, 2016a). Section 3.2 of the code indicates that drainage for surface water runoff should be designed for 1:20 or 1:30 year events rather than 1:1 or 1:10 year events, in new towns and new development areas. This is encouraging, as such standards compare well with other advanced economies in East Asia such as Hong Kong and Singapore (where infrastructure is designed for at least 1:50 year events in both towns and new developments (Public Utilities BOARD, 2015; DSD, 2012). However, the GB50014-2006 code of practice does not indicate how drainage design should be undertaken in older towns or districts, or indicate how current practices should be integrated with new, more sustainable drainage practice.

#### 4. Discussions and conclusion

It is expected that adoption and implementation of sustainable urban water management policy and practices will improve in China as the Sponge City pilot studies near completion (the first batch of which are due towards the end of 2017). The country is by now well-used to managing water issues via a complex governance system in which related governing institutions are many. For example, whilst urban flood issues are managed by the Ministry of Water Resources, urban water pollution is managed by the Ministry of Environment. Similarly, whilst vegetation, trees and deforestation issues that involve soil water interactions and soil erosion are managed by the Ministry of Forestry, all other land-use planning is managed by the Ministry of Planning and Construction Bureau. All related institutions have their own codes of practice and legislated practices and policies: predominantly at municipality level due to a decentralisation of the governance system (Cosier

and Shen, 2009). In light of the rapid continuous urban developments and the impacts of continuing climate change however, it will be difficult to solve every urban water issue simultaneously. It is more realistic to expect a gradual and continuous change based on continuous learning and feedback about what is actually required to implement such a highly ambitious program as is the concept of the Sponge City.

The Sponge City concept can however, act as a lightning-rod to help co-ordinate and integrate current urban water management systems. As has been discussed above, a number of codes of practice have already been revised to better cope with the new Sponge City guidelines (e.g. roads and green space planning). In this way, the concept has at very least initiated a process by which urban water issues need to be considered in unison with all planned land-use change, and planning applications for new developments, which is both a promising and potentially game-changing prospect in China.

The Sponge City guideline document improves on existing urban drainage guidance by stipulating that provision has to be made to drain runoff from up to 1:30 year 24-h rainfall, as opposed to the current minimum guidelines. Most of the Chinese cities at the moment are equipped with the land drainage system are only able to withstand the runoff at 1:1 year rainstorm that should be only equivalent at about (187 mm/24 h). Therefore, the Sponge city program has already improved to deal with the urban runoff. However, if the rainstorms are intensive or greater than 1:30 year 24-h rainfall events, the current sponge system are unable to withstand according to the Sponge city construction guideline (Ministry Of Housing And Urban-Rural Development, 2014). Nevertheless, the guidelines do provide an opportunity for municipal urban planning and water authorities to deliver some functionality of infrastructure during higher intensity events.

Table 1 for example shows that whilst permeable pavements are not the most attractive infrastructure item, their relatively low construction and maintenance costs can provide a cost-effective way of reducing runoff and removing stormwater pollutants (e.g. suspended solids) by 80–90%. Other measures such as green roofs, bio-detention measures, artificial pond and wetlands, raingardens, bio-swales and vegetation buffers can also enhance ecological function and encourage ecosystem diversity, providing more diverse habitats for a range of organisms. The introduction of the Sponge City concept therefore can thus deliver multiple benefits of increased stormwater infiltration, purification, and storage: and facilitates the potential for grey-water reuse during a dry season (Ministry Of Housing And Urban-Rural Development, 2014).

The next stage for the Sponge City concept is its gradual adoption within a wider, national planning policy. In this respect, China may learn from countries like the UK which is in the process of producing planning guidance that aims to integrate the existing planning process

within flood-risk appraisal and assessment practices: for example, the Planning Policy Statement 25 (PPS25) (Department For Communities And Local Government, 2007); and the National Planning Policy Framework (NPPF) (Department For Communities And Local Government, 2012). These UK policies have proven successful in restricting new developments in areas at risk of flooding, and in identifying ongoing flood risks from surface water, rivers and coasts. This has been achieved by giving Local Planning Agencies (LPAs) the authority to reject new development applications if the proposal fails against the flood risk appraisal, or approve developments on condition that the developers are responsible for flood-risk mitigation and ensuring that new developments are protected to acceptable standards. This approach has reduced flood-risk within many new towns and developments, and also reduced unnecessary public financing of additional flood protection measures. The NPPF too (and previously the PPS25) integrates sustainability assessments and environmental impact assessment tools to address wider concerns of health, economic activity, environmental ecology, and cultural heritage. This approach helps to co-ordinate institutions (e.g. Local Government Authorities and the Environment Agency), and helps planners, flood engineers and decision makers to understand their roles and collaborate with each other, and so deliver effective long-term strategic plans for districts, cities or regions.

It is recommended therefore, that comparable authorities in China strengthen their international cooperation and collaboration so that they are able to gain from the experience of institutions in the UK (i.e. SuDS), US (i.e. LID), Australia (i.e. WSUD), or New Zealand (i.e. LIUDD). The 30 Chinese Sponge City pilot areas should also adapt and utilise the related urban-planning concepts, theories and methods, in a way that is suitable for Chinese cities (in which substantial drainage modification has occurred through time).

In conclusion, we can say that the Sponge City concept is, without doubt, influential and revolutionary in its approach to land-use planning; urban water-resource management; urban flood and climate risk mitigation; ecological enhancement; and social wellbeing. Similarly, it is encouraging that the Chinese Government has shown itself to be committed to exploration of new ideas, and in introducing the Sponge City concept has demonstrated its willingness to learn from similar concepts overseas (e.g. LID, SuDS, and WSUD). However, whilst many of its aims have already been delivered on (e.g. Beijing Olympic city and North Beijing area) (Liu et al., 2016), there are many challenges (e.g. finance and cost of sustaining sponge city program in larger areas in cities, the co-ordinations across bureaus, the public perceptions and support, the evaluation of effectiveness of sponge city program, etc.) that remain.

Whilst it is necessary to wait for the completion of the first and second batch of Sponge City pilot projects to be completed before a proper assessment of their success or failure can be made, improvements to the planning and construction process can continue to be made to the Sponge City guidelines initiated by the program. It is hoped however, that the eventual assessment process and outcomes of the project will be as transparent and open as possible, thus allowing stakeholders not directly involved in any project to learn and fine-tune their own practices. More generally, it is expected that the impact of the Sponge City concept on land-use planning policy will be significant, as related practices draw from the empirical evidence of the pilot study experiences for years to come.

## Declaration

On behalf of all co-authors of this manuscript, I myself (Dr Faith Chan) as a correspondent author of this manuscript (titled: “Sponge City” in China – a breakthrough of planning and flood risk management in the urban context) declared that there is no conflict of interest of this manuscript.

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